Variable Stars in the Field of the Open Cluster NGC 2204

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ABSTRACT

We present the results of a variable stars search in the field of the old open cluster NGC 2204. Five new variables were found, four of them being eclipsing binaries. The sample includes a detached binary located at the turnoff, a W UMa – type system, and an interesting detached low-mass binary with a period of $0.45^{\rm d}$ which, however, is a foreground object. We provide V-light curves and finder charts for all variables together with color-magnitude diagrams of the cluster. For four variables incomplete I-light curves are also provided.

Key words: *open clusters and associations: individual: NGC 2204 - binaries: eclipsing*

1 Introduction

NGC 2204 (Mel 44) is a rich but rather loose cluster in Canis Major, centered at $(l,b)=(226.01,-16.11)$. It is located 4 kpc away from the Sun, 11.1 kpc away from the galactic center and 1.1 kpc below the galactic plane (Kassis et al. 1997). At that heliocentric distance its angular diameter of $15'$ (Hawarden 1976) corresponds to the linear diameter of $\sim$17 pc. It is only weakly reddened, with estimates of $E(B-V)$ ranging from 0.07 (Mermilliod and Mayor 2007) to 0.13 (Kassis et al. 1997). Maps of interstellar reddening by Schlegel et al. (1998) imply that reddening in the cluster should not exceed $E(B-V)=0.10$. Estimates of its age vary from 0.78 Gyr (Piatti *et al.* 2003) to 2.5 Gyr (von Hippel 2005). Various measurements of [Fe/H] have yielded values between -0.47 (Hou *et al.* 2002) and -0.32 (Krusberg and Chaboyer 2006), consistently showing that the cluster is metal-deficient.

Deep CCD photometry of NGC 2204 was obtained by Kassis *et al.* (1997), who also performed isochrone fitting. They derived an age of $1.6^{+0.9}_{-0.3}$ Gyr, with uncertainties ascribed mainly to the poorly known metallicity. Mermilliod and Mayor (2007) obtained spectra for 25 red giants belonging to the cluster. The sample included all red clump stars together with those brighter than the clump. Based on these data, they found the mean radial velocity of the cluster to be equal to 91.38 ± 0.30 km s^{-1}.

No survey of variable stars in NGC 2204 has been reported so far. The present study is based on archival observations performed within the long-term program of CCD search for short-period variables in selected star clusters (see e.g. Mazur *et al.* 1999 and references therein). Particularly interesting and valuable among those variables are detached eclipsing binaries, which at the moment enable the most accurate determinations of stellar masses, radii and luminosities, thus providing an excellent check on stellar evolution theory and a means for direct distance determination.

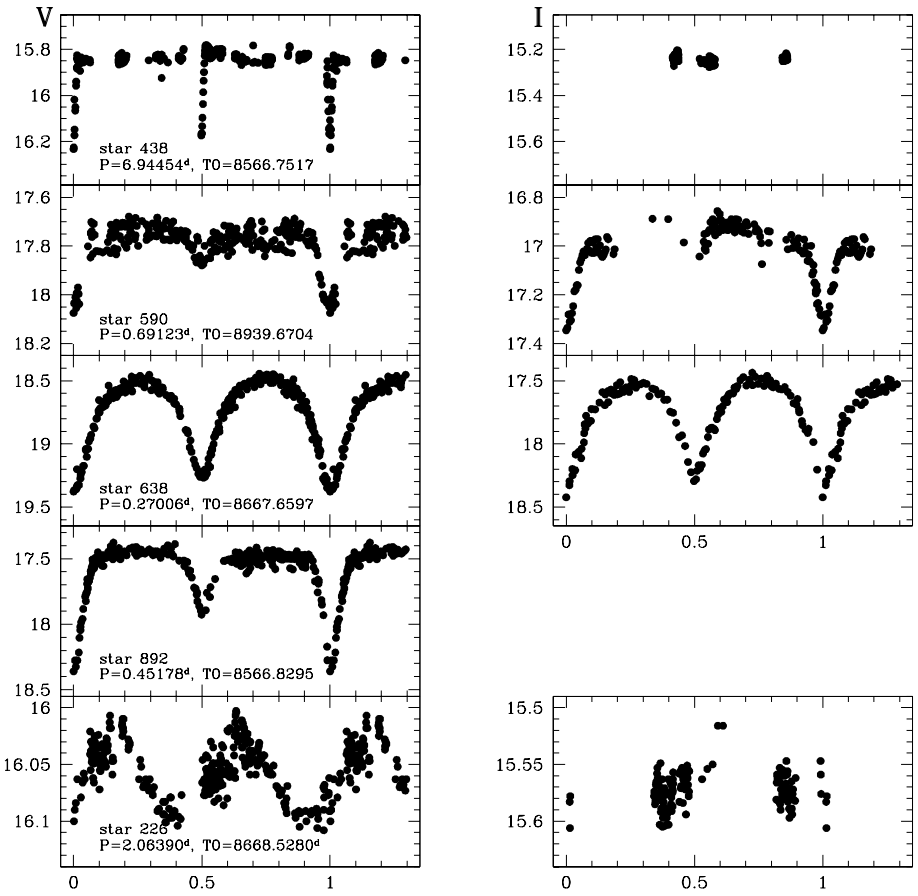

Figure 1: Phased light curves. T0 are moments of minima on JD-2440000. The star V892 was visible in only one I-frame (the single one taken with Tek #3).

2 Observations and Data Reduction

The data were collected with the 1-m Swope telescope at Las Campanas Observatory on 24 nights between October 1991 and January 1993. The cluster was observed with three different CCD cameras: Tektronix #1 (1024×1024 pixels; 12 arcmin FOV; 0.70 arcsec/pixel), Tektronix #2 (1024×1024 pixels; 10.4 arcmin FOV; 0.61 arcsec/pixel) and Tektronix #3 (2048×2048 pixels; 21 arcmin FOV; 0.61 arcsec/pixel). Altogether, 485 frames were taken (310, 136, 29 and 10 in V, I, B and U filters, respectively). The exposure times ranged from 10 to 900 s.

The preliminary processing of the raw data was performed under IRAF*. Tektronix #3 frames were cropped to 1200×1200 pixels (12 arcmin FOV). All frames were bias-subtracted and flattened with median-averaged sky flats. Because of problems with the filter the flattening did not work well for U-frames, and the resulting U-magnitudes are less reliable than B, V or I ones.

The photometry was performed with the DAOPHOT/ALLSTAR package (Stet-

*IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the AURA, Inc., under cooperative agreement with the NSF.

son 1987). The reduction procedure started from the identification of stars with subroutine FIND, followed by aperture photometry with subroutine PHOT. Next, based on about a hundred isolated stars, a PSF varying quadratically with (x,y) coordinates was constructed for each frame, and used for the profile photometry with subroutine ALLSTAR. The images were inspected visually, and for each camera and each filter one of the best frames was chosen as a template. Instrumental magnitudes of template stars were transformed to the standard system using the data of Kassis *et al.* (1997) available in the WEBDA database. For each frame taken with the same camera and filter the template stars were identified by means of transformations of (x,y) coordinates, and ALLSTAR photometry for those frames was transformed to the standard system with the template serving as an intermediary. Finally, α_{2000} and δ_{2000} were determined for all stars found in the V-filter. The transformation from rectangular to equatorial coordinates was based on 1557 stars from the USNO-A2 catalogue with $06^{\rm h}16^{\rm m}01^{\rm s} > \alpha_{2000} > 06^{\rm h}14^{\rm m}57^{\rm s}$, and $-18^\circ31'43'' > \delta_{2000} > -18^\circ46'46''$.

3 Variable Stars

In order to effectively use the available information, a field of $12' \times 12'$ was analyzed, so that only the photometry from Tektronix #2 was missing for some stars. For that field all photometric data were combined into a database, and searched for periodicities with the program TATRY kindly provided by Alex Schwarzenberg-Czerny. This program is suitable for the detection of various types of variables based on the analysis of variance method (Schwarzenberg-Czerny 1996). Four evident variables were found, whose light curves are shown in Fig. 1. An inspection of cluster's color-magnitude diagrams (Fig. 2) suggests that stars V438, V590 and V638 indeed belong to NGC 2204. They are located on or slightly above the cluster main-sequence, which is consistent with their binary nature. The star V892 must be a foreground object as it is located far redwards of the cluster main sequence. Finder charts for the detected variables are shown in Fig. 3.

Star V438 is a clearly detached MS binary on a circular orbit. Within observational errors its V- curve is flat between the minima. The minima are deep and similar in shape, indicating that the system is seen nearly edge-on, and its components are almost identical. Unfortunately, none of the minima occurred during relatively scarce I-observations. In Fig. 2 star V438 is located practically at the turnoff. This object seems to be well suited for spectroscopic observations which would allow for an accurate determination of the masses of its components and a much better estimate of the age and distance of NGC 2204.

Star V590 is blended with a brighter but resolved neighbor, resulting in a rather poor photometry. Judging from the V-curve it is another detached binary, however inclined to the observer at an angle significantly different from 90°. The I-curve does not entirely cover the secondary minimum, but it seems to indicate effects of proximity, consistent with the short period of this system.

Star V638 is a contact binary with primary minima $\sim$1 mag deep, and secondary minima only $\sim$0.1 mag shallower. Large amplitude of light variations indicates mass ratio close to unity and inclination close to 90 deg. Using empirical calibration of Rucinski and Duerbeck (1997) we have estimated absolute magnitude of the variable at $M_{\rm V} = 5.27$. With $V_{max} = 18.53$ this implies an apparent distance modulus $(m-M)_{\rm V} = 13.26$ what is very close to distance

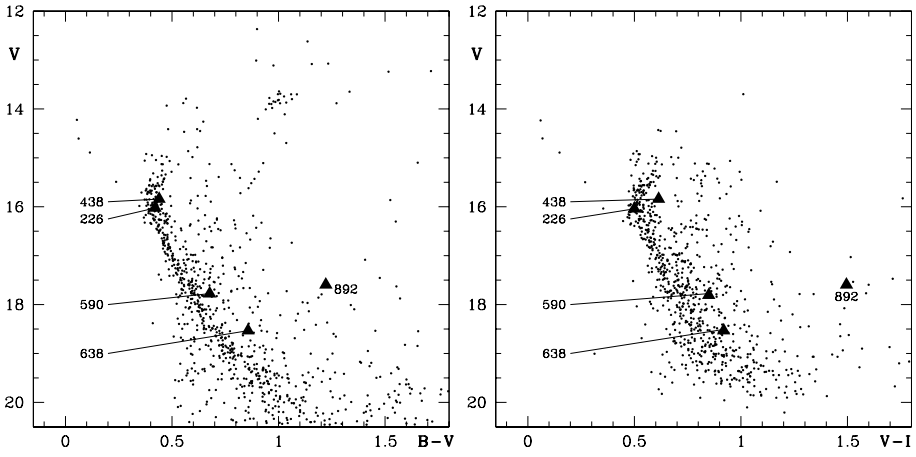

Figure 2: Color-magnitude diagrams of NGC 2204 with locations of the discovered variables. Most stars brighter than 14 mag in I were overexposed.

Table 1: Coordinates and photometric parameters of variables from NGC 2204 field. $(B-V)$ and $(V-I)$ are given at maximum V.

Star	RA_{2000}	Dec_{2000}	V_{MAX}	ΔV	$(B-V)$	$(V-I)$	Type
438	06:15:33.85	-18:39:20.2	15.84	0.45	0.55	0.61	Ecl
590	06:15:29.92	-18:40:40.1	17.75	0.38	0.79	0.85	Ecl
638	06:15:23.40	-18:41:14.2	18.45	0.93	0.94	0.92	Ecl-EW
892	06:15:55.42	-18:44:51.7	17.45	0.95	1.17	1.50	Ecl
226	06:15:46.10	-18:37:6.70	16.04	0.08	0.52	0.50	Ell?
904	06:15:17.82	-18:45:07.1	18.28	<0.05	$0.28^\star$	0.91	?

$^\star(U-B)=-0.9$

modulus of the cluster estimated at $(m-M)_V=13.28$ by Mermilliod & Mayor (2007). Hence, star V638 is a very likely member of NGC 2204.

Star V892 – a detached binary with $B-V=1.17$ and a period of 0.45^d – is the most interesting among the new variables. Its short period together with the undetectable proximity effects suggest that it is composed of MS stars. Such system can be located high above the MS of the cluster only if it is a foreground object. As the primary minimum is very deep, it must be seen nearly edge-on. A much shallower secondary minimum indicates a significant difference in surface brightness of the components. To roughly estimate the parameters of the primary we can neglect the contribution of the secondary and assume that the reddening of the system is two times smaller than that of NGC 2204. We get the true $B-V$ of $\sim$1.25, *i.e.* an effective temperature of $\sim$4300 K (spectral type K6-K7), which on the Main Sequence translates into $\mathcal{M}_\star \approx 0.6 M_\odot$ and $M_V \approx 8$ (Sekiguchi and Fukugita 1999; Baraffe *et al.* 1998). Since V is equal to 17.5, star V892 should be located at a distance of about 1 kpc from the Sun, consistent with the assumed value of the reddening. An equally rough estimate of the parameters of the secondary yields $M_V \approx 8.5$ and spectral type K7-K8.

Star V226 shows a sinusoidal light curve with a full amplitude of about 0.08 mag in the V band. It may be an ellipsoidal variable, but our data are not sufficient for an unambiguous classification of this object.

Finally, we found a potentially interesting blue object - star V904 with $(U-B)=-0.9$, $(B-V)=0.28$ and $V=18.3$ which may be variable with a period of

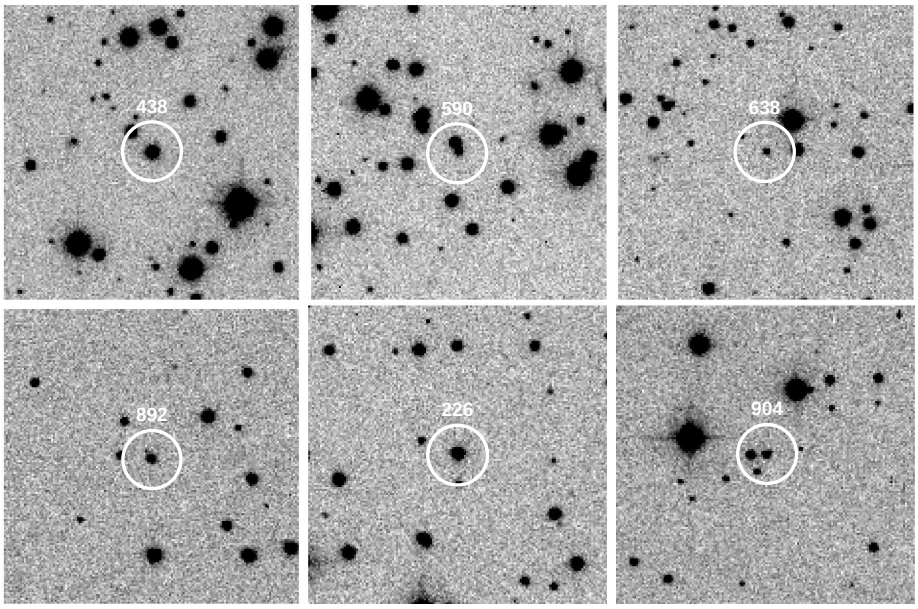

Figure 3: The V-band finder charts for the new variables. Each chart is $90''$ on a side with North up and East to the left.

$\sim 1.4^{\rm d}$ or $\sim 2.8^{\rm d}$ and an amplitude smaller than $\sim$0.05 mag. We could not identify it with any cataloged X-ray source, and in the future it might be worthwhile to take its spectrum. One may note that the strongly blue $U-B$ color of star V904 is incompatible with its $B-V$ and especially $V-I$ color. This may indicate that we are dealing with a composite object. Finder charts for stars V226 and V904 are also shown in Fig. 3.

None of the four blue straggler candidates visible in Fig. 2 showed any evidence for variability with a full amplitude exceeding 0.05 mag.

4 Discussion

We performed a search for variable stars in the field of the old open cluster NGC 2204 which yielded four new eclipsing binaries. One of them (star V438) is located at the turnoff, and may be used for an accurate determination of the age and distance of the cluster. Another one (star V892, a foreground object) is an interesting detached binary, most likely composed of two late K-type MS stars. Such systems are very rare – Ribas (2006) lists only 14 members of double lined binaries with masses below $0.8{\rm M}_\odot$ – and very puzzling, as their observed radii disagree with theoretical predictions. In the $0.4-0.8{\rm M}_\odot$ range the models predict values which are consistently too small by 5 - 15%. Since the current accuracy of the measurements reaches a few percent in both mass and radius, these differences are undoubtedly significant. Thus, star V892 is potentially very valuable. At $V=17.5$ mag its spectrum could be easily obtained on a modern large telescope. If our estimates are correct, and lines of both components are visible, it would help to solve the problem of discrepancies on the lower Main Sequence.

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